

Description

THERMALLY STABLE LEAN NO_x TRAP

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to lean NO_x traps with improved aging characteristics, and in particular, to lean NO_x traps that resist degradation of NO storage capacity upon thermal aging.

[0003] 2. Background Art

[0004] Environmental concerns and governmental regulations have been a continuing impetus for improvements in pollution control from automotive vehicles. The treatment or removal of noxious combustion by-products from the exhausts of such vehicles is a major focus of such efforts. Typically these combustion by-products include incomplete combustion by-products such as carbon monoxide and hydrocarbons. Moreover, the exhausts of these vehicles also include various nitrogen oxides and sulfur oxides. It is desirable and mandated that each of these com-

pounds be reduced to a level that meets certain governmental regulations during vehicle operation.

[0005] Lean engines operate under fuel-lean conditions, i.e., a net oxidizing condition. Such an exhaust environment poses unique requirements for treating carbon monoxide, hydrocarbons, and especially NO_x . NO_x is the most difficult to convert because the exhaust gas is oxidizing yet NO_x needs to be reduced in order to convert it to N_2 . One of the most promising treatments of NO_x from lean-burn operation today involves the use of nitrogen oxide absorbent material with precious metals or lean NO_x traps. Such NO_x trap materials are able to absorb nitrogen oxides during lean-burn operation and to release them when the oxygen concentration in the exhaust gas is lowered. Accordingly, these traps are used with engine systems that operate primarily in a lean air/fuel ratio. However, when it is desired to purge the traps of NO_x , the exhaust entering the trap is made fuel richer – either stoichiometric or fuel rich of stoichiometric.

[0006] One of the most critical problems for wide application of lean NO_x traps ("LNT") is the thermal stability/durability of the trap. Typically a well made LNT will store and convert NO_x to N_2 with high efficiency (> 90%) when the trap has

not been exposed to high temperature (e.g. $> 750^{\circ}\text{C}$) aging. However, when the trap is aged at high temperature, the trap degrades quickly, losing the high efficiency of storing and converting NO_x . In practice, such a high temperature can be expected in the exhaust system where a trap is located, in cases such as high speed/load operation, engine misfire, lean NO_x trap desulfation, etc. This relatively poor thermal stability and or durability has hindered the wide application of the LNT trap, or the lean burn engines.

- [0007] Our studies show that an important mechanism for deactivation of lean NO_x traps after high temperature aging is the loss of storage efficiency. And the critical modes for the loss of storage efficiency are the loss of oxidation activity of NO to NO_2 , and the loss of proximity between the precious metal and the trapping element after thermal aging, thereby limiting the spillover of oxygen atoms from the precious metal to the trapping element to convert the (barium) nitrite to (barium) nitrate, or the NO_x species from the precious metal to the trapping element to form nitrates.
- [0008] Accordingly, there exists a need for lean NO_x traps with improved storage efficiency and in particular with im-

proved oxidation activity and proximity of the active components after high temperature aging.

SUMMARY OF INVENTION

[0009] The present invention overcomes one or more problems of the prior art by providing in one embodiment a method of removing harmful gases from an automobile exhaust. The method of the invention comprises contacting a NO_x trap composition with a first exhaust gas mixture at a temperature of at least 200°C. The first exhaust gas mixture includes exhaust gases from an internal combustion engine operating in a fuel-lean condition. The method of the invention is specifically characterized by the NO_x trap composition which includes a precious metal, a NO_x absorber material, an oxide that inhibits the decrease in NO_x storing ability of the NO_x trap composition, and a support material. After NO_x has been absorbed onto the NO_x absorber material, the NO_x trap composition is then contacted with a second exhaust gas composition at a temperature of at least 200°C. In this step, the second exhaust gas mixture includes exhaust gases from an internal combustion engine operating in a fuel-rich condition. A particularly important aspect of the invention is the oxidation and spillover promoting function of the oxide that

inhibits the decrease in NO_x storing ability of the NO_x trap composition. For example, the incorporation of Mn and Mg into a NO_x trap formulation (with Pt, Ba on Al) significantly improves thermal durability and in particular, the addition of Mn improves the oxidation activity significantly, especially after the LNT is aged. It is also believed that the addition of Mg lowers the defect energy at the Ba–Mg boundary, resulting in more defect formations for Ba, thereby promoting the spill over effect at the grain boundaries of these defects.

- [0010] In another embodiment of the invention, a lean NO_x trap executing the method of the invention is provided. The composition of the NO_x trap of this embodiment is the same as that set forth above. Specifically, the NO_x trap includes a sufficient amount of an oxide to inhibit a decrease in NO_x storing ability when the NO_x trap composition is thermally aged.
- [0011] In yet another embodiment of the invention, an automobile exhaust system which implements the method of the invention by incorporating the NO_x trap of the invention is provided.

BRIEF DESCRIPTION OF DRAWINGS

- [0012] FIGURE 1A is a plot of the oxidation activity (determined

from the conversion of NO to NO₂) of an unaged commercially available NO_x trap composition;

- [0013] FIGURE 1B is a plot of the oxidation activity (determined from the conversion of NO to NO₂) of an aged (at 850°C, for 50 hr in an oxidizing environment) commercially available NO_x trap composition;
- [0014] FIGURE 2A is a plot comparing the oxidation activity of aged (900°C, 12 hr, 6% enriched air aging) test sample prepared from sample catalyst A;
- [0015] FIGURE 2B is a plot comparing the oxidation activity of aged (900°C, 12 hr, 6% enriched air aging) test sample prepared from sample catalyst B;
- [0016] FIGURE 2C is a plot comparing the oxidation activity of aged (900°C, 12 hr, 6% enriched air aging) test sample prepared from sample catalyst C;
- [0017] FIGURE 2D is a plot comparing the oxidation activity of aged (900°C, 12 hr, 6% enriched air aging) test sample prepared from sample catalyst D;
- [0018] FIGURE 3 provides a series of plots comparing the NO storage capacity of test samples prepared from sample catalysts A–E before aging; and
- [0019] FIGURE 4 provides a series of plots comparing the NO storage capacity of test samples prepared from sample

catalysts A–E after aging.

DETAILED DESCRIPTION

[0020] The following examples illustrate the various embodiments of the present invention. Those skilled in the art will recognize many variations that are within the spirit of the present invention and scope of the claims.

[0021] In an embodiment of the present invention, a method of removing harmful gases from an automobile exhaust is provided. Such automobile exhausts include NO_x , CO, and hydrocarbons. The method of the invention comprises contacting a NO_x trap composition with a first exhaust gas mixture at a temperature of at least 200°C. The first exhaust gas mixture includes exhaust gases from an internal combustion engine operating in a fuel-lean condition (i.e., oxygen rich). Moreover, the NO_x trap composition used in the method includes a precious metal, a NO_x absorber material, an oxide that inhibits the decrease in NO_x storing ability of the NO_x trap composition, and a support material. After, NO_x has been absorbed onto the NO_x absorber material, the NO_x trap composition is then regenerated by contact with a second exhaust gas composition at a temperature of at least 200°C. In this step, the second exhaust gas mixture includes exhaust gases from an in-

ternal combustion engine operating in a fuel-rich condition.

[0022] In another embodiment of the invention, a thermally stable NO_x trap composition is provided. The thermally stable NO_x trap composition is the same composition used in the methods of the invention set forth above. Moreover, the NO_x trap composition of this embodiment is advantageously included in a vehicle exhaust system for removing NO_x from the exhaust of an internal combustion engine. The NO_x trap composition is further characterized in that a NO_x trap incorporating the NO_x trap composition has a NO_x storage efficiency of at least 5% at a temperature of 400°C after aging of the NO_x trap at 900°C for 12 hr under 6% (volumetric percent) oxygen enriched air. In a variation of the invention, a NO_x trap incorporating the NO_x trap composition has a NO_x storage efficiency of at least 20% at a temperature of 400°C after aging of the NO_x trap at 900°C for 12 hr under 6% (volumetric percent) oxygen enriched air. In another variation of the invention, a NO_x trap incorporating the NO_x trap composition has a NO_x storage efficiency of at least 30% at a temperature of 400°C after aging of the NO_x trap at 900°C for 12 hr under 6% (volumetric percent) oxygen enriched air.

[0023] The oxide which is included in the NO_x trap composition used in the method of the invention is characterized as conveying improved thermal stability onto the NO_x trap. The oxide inhibits the decrease in NO_x storing ability of the NO_x trap composition. Specifically, a NO_x trap with this oxide will have less of a drop in NO_x storing ability than a similar trap not having such an oxide. Suitable oxides for inhibiting the decrease in NO_x storing ability of the NO_x trap composition include, for example, oxides selected from the group consisting of oxides of magnesium, oxides of manganese, and combinations thereof. In accomplishing the goal of improving thermal stability, the amounts of the oxide in the NO_x trap composition require special attention. If the amount of oxide is too low (less than 1% of the NO_x trap washcoat) the improvement in stability is insignificant. As used herein, "washcoat" refers to coatings of the NO_x trap compositions applied to a substrate by washcoating. In the washcoating process, an aqueous solution contain precursors to the components of the NO_x trap are applied to the substrate and subsequently heated and calcined (see the description below). If the amount of the oxide is too high (great than 30% of the NO_x trap washcoat), the NO_x storage capacity is adversely

affected. Presumably, this adverse effect is the result of the oxide replacing too many sites which should be occupied by the NO_x absorber (i.e., the barium oxide). Therefore, in some variations of the invention, the oxide is present in an amount from about 1 to 30% of the total weight of the NO_x trap washcoat. In other variations of the invention, the oxide is present in an amount from about 5 to 20% of the total weight of the NO_x trap washcoat. In still other variations of the invention, the oxide is present in an amount from about 5 to 15% of the total weight of the NO_x trap washcoat.

[0024] The NO_x trap composition used in the method of the invention also includes a NO_x absorber and a precious metal. Typically, the NO_x absorbers are basic oxides. Suitable basic oxides are selected from the group consisting of oxides of alkali metals, oxides of alkaline earth metals, oxides of rare earth metals, and combinations thereof. In a variation of the invention, the NO_x absorber is selected from the group consisting of cesium oxide, praseodymium oxide, strontium oxide, barium oxide, and combinations thereof. In one variations of the invention, the NO_x absorber is present in an amount from about 5 to 50% of the total weight of the NO_x trap washcoat. In an-

other variation, the NO_x absorber is present in an amount from about 5 to 40% of the total weight of the NO_x trap washcoat. In still other variations, the NO_x absorber is present in an amount from about 10 to 25% of the total weight of the NO_x trap washcoat. The precious metal used in the NO_x trap and method of the invention is typically a metal selected from the group consisting of platinum, palladium, rhodium, and combinations thereof. In one variations of the invention, the precious metal is present in an amount from about 0.1 to 10% of the total weight of the NO_x trap washcoat. In another variation, the precious metal is present in an amount from about 0.5 to 5% of the total weight of the NO_x trap washcoat. In still other variations, the precious metal is present in an amount from about 0.5 to 3% of the total weight of the NO_x trap washcoat.

[0025] Any number of materials known to one skilled in the art may be used for the support material. The function of the support material is to provide a medium upon which to disperse the precious metal, the NO_x absorber, and the oxide and to provide increased surface area for the NO_x trap composition. Suitable support materials include, for example, powdered alumina.

[0026] The NO_x trap composition of the invention is fabricated by impregnating support material with the NO_x absorber and the precious metals. The support material is washcoated onto a monolithic substrate (such as cordierite) having from about 400 to 900 cells/ ft^2 . In such a washcoating process, an aqueous solution containing nitrate salts corresponding to the metals in the compositions set forth above are deposited onto the substrate to form a pre-coated substrate. Next, the precoated substrate is dried (typically at room temperature). Optionally, the precoated substrate is further dried at a temperature from about 80°C to about 105°C. Finally, the precoated substrate is calcined at a temperature from about 600°C to 650°C. The substrates onto which the NO_x trap composition may be coated are any substrates suitable for automobile exhaust applications. Often these substrates are monolithic metallic or ceramic honeycombed structures having numerous small channels. An example of a particularly useful substrate material is cordierite. In a variation of the preparation of the NO_x trap composition of the invention, the component are combined such that the Precious metal is added first in a manner such that the oxide will be in close proximity to the Precious metal. The Precious metal

and stabilizing oxide are then individually calcined together to optimize the proximity between the oxidizing components (NO to NO_2) and trapping components. If these components are either too close or too far apart, a lower oxidation activity or a trapping efficiency is obtained. Similarly, it is desirable to have the NO_x absorber material (i.e., Ba) and the stabilizing oxide (e.g., Mg) close to each other so that the boundary effects (of Mg) promote defects density and hence maximize spillover.

"Spillover" as used herein refers to the transfer of oxygen atoms from the precious metal to the trapping element to convert the (barium) nitrite to (barium) nitrate or the transfer of NO_x species from the precious metal to the trapping element.

[0027] In a particularly useful embodiment of the invention, a method of removing harmful gases from an automobile exhaust containing NO_x , CO, and hydrocarbons is provided. The method of this embodiment comprises contacting a NO_x trap composition with a first exhaust gas mixture at a temperature of at least 200°C, the first exhaust gas mixture comprising exhaust gases from an internal combustion engine operating in a fuel-lean condition (for example, an air-fuel ratio of about 40). The NO_x

trap composition of this embodiment comprises a precious metal, barium oxide, a stabilizing oxide that inhibits the decrease in NO_x storing ability of the barium oxide, and a support material. The specifics of the selection of and the amounts of the precious metal, the stabilizing oxide, and the support material are the same as those set forth above. After the contacting of the NO_x trap under lean conditions for about 60 seconds, the NO_x trap is then cycled through a regeneration step. Regeneration is achieved by contacting the NO_x trap composition with a second exhaust gas composition. This second exhaust gas composition is different than the first exhaust gas composition and includes exhaust gases from an internal combustion engine operating in a fuel-rich condition. It should be noted that the stoichiometric air fuel ratio for gasoline operated vehicles is about 14.6. Therefore a fuel-lean condition has an air/fuel ratio greater than 14.6 and a fuel-rich condition has an air/fuel ratio less than 14.6.

[0028] The following examples illustrate the various embodiments of the present invention. Those skilled in the art will recognize many variations that are within the spirit of the present invention and scope of the claims.

[0029] With reference to Table 1, catalyst samples A-D are prepared. The following preparation of a powder sample containing Mn and Mg is representative of the preparation of catalyst samples A-D. About 20g Degussa fumed Al_2O_3 was suspended in 250 ml of D.I. water at 70°C and stirred for 2 hr. Next 2% Pt(0.408g Pt) metal from a soluble chloride salt is added. Stirring is continued until the suspension is nearly dry, at which time an additional 150 ml of D.I water is added. Stirring is allowed to continue until the suspension becomes nearly dried and then oven dried at 80°C in air for 6 hr. The material is then calcined at 600°C in air for 6 hr in air with 6% excess O_2 . Next, the sample is milled with 100 ml. D.I. H_2O and enough Mn from $\text{Mn}(\text{NO}_3)_2$ to yield a deposition of 10% Mn_2O_4 based on Al_2O_3 present. The required amount is about 2.53g $\text{Mn}(\text{NO}_3)_2$. After wet milling for 15 hr and inspection, the material is stirred until nearly dried and then oven dried for 6 hr at 80°C in air. The sample is then calcined for 6 hr at 600°C in air with 6% excess oxygen. A combination of 9% Mg from $\text{Mg}(\text{NO}_3)_2$ (7.28g.) and 9% Ba from $\text{Ba}(\text{C}_2\text{H}_3\text{O}_2)_2$ (3.68g.) is added to the sample in a single step to 100 ml water and wet milled for 20 hr. Next, the sample is stirred at 70°C until nearly dry and then oven dried for 6 hr at

80°C in air. Finally, the sample is calcined for 6 hr at 600°C in air with 6% excess oxygen.

Table 1. Sample compositions

<i>Catalyst sample</i>	<i>Composition</i>
A	2% Pt, 20% BaO on alumina
B	catalyst sample A + 6% Mn
C	2% Pt, 10% BaO, and 10% MgO on alumina
D	2% Pt, 10% BaO, 10% MgO, and 6% Mn on alumina
E	proprietary composition from a commercially available monolith

[0030] Catalyst sample E is prepared from a commercially available proprietary monolith (a NO_x trapping monolith) which is known to have superior performance. Although there are a number of differences (e.g. trapping elements, washcoat loading, preparation engineering, etc.) between the commercially available proprietary monolith and sample A-D, the precious metal loading for each of the samples are kept close. The commercially available proprietary monolith has about 0.53% Pt and 0.05% of Rh for a total of 0.58% (Pt + Rh on total weight base). Samples A-D have about 2% Pt (nominally, washcoat basis, no Rh), the total washcoat loading is 27.3%. Hence, the Pt loading is 0.55% Pt (total weight basis).

[0031] For each of the experimental results illustrated in Figures 2 – 4, a test sample is prepared by combining 100 mg of powder catalyst samples A–D with 200 mg blank cordierite in the same particle sizes (40 – 60 mesh). This is to mimic the typical catalyst washcoat composition (30% washcoat) and to minimize temperature variation during the reaction. Preparation of a test sample from catalyst sample E is different from catalyst samples A–D. The monolith is crushed to 40 – 60 mesh size but not mixed with blank cordierite. In each experiment, the samples are exposed to a feed gas with a total flow rate of about 750 ml/min. This would amount to an equivalent space velocity at approximately 80 k hr^{-1} . The feed gas contains 500 ppm NO, 10% CO_2 , 10% H_2O , with N_2 balance. Percentages of gaseous components as used herein are volume percentages unless otherwise stated. In addition to the components set forth above, the feed gas contains additional components depending on the particular experiment being performed (i.e., oxidation activity or NO storage efficiency determination.) For the oxidation activity experiments, the feed gas is in a lean condition having about 6% O_2 . Oxidation efficiency means the volumetric percent of NO fed to the NO_x trap which is converted to NO_2 . For the

NO storage capacity determinations, the samples go through a lean/rich cycle mode, with 60 second lean and 20 second rich. The efficiency is calculated from an average of 3 lean periods at the stated temperature. The composition of the feed gas during the lean condition is the same as set forth above while the composition of the feed gas during the rich condition further includes 4% CO and 1.3% H_2 (zero O_2). The feed-gas does not contain hydrocarbons or sulfur during these reactions unless specified. Each of the samples are pretreated prior to the oxidation activity and NO storage capacity experiments in the following manner. The samples are heated to 600°C at 10°C/min under rich feed (no CO_2) and stayed at 600°C for 20 min. Then the powder is saturated with NO_x and O_2 at 600°C for 10 min, ramping down (oxidation) to 100°C at 10°C/min with CO_2 , H_2O , NO, O_2 , N_2 as described above.

[0032] Figure 1 shows the oxidation efficiency as a function of temperature of a commercially available monolith before and after thermal aging. These plots clearly demonstrate significant loss of oxidation activity in the temperature range from about 150°C to about 550°C. Figures 2A-D provides a series of plots comparing the oxidation activity of aged (900°C, 12 hr, 6% enriched air aging) test samples

prepared from catalyst samples A–D. The test sample prepared from test sample A which has 2% Pt, 20% BaO on Alumina but no stabilizing oxide exhibited a relatively low oxidation efficiency of less than 10% over the entire temperature range from about 150°C to about 550°C. Each of the test samples prepared from catalyst samples B–D which have one or more oxides showed greater than 15% oxidation efficiency over at least a portion of the temperature range studied. The test sample prepared from catalyst sample B (catalyst sample A + 6% Mn) exhibited greater than 15% oxidation efficiency in the temperature range from about 350°C to about 550°C, and a greater than 30% in the temperature range from about 400°C to about 500°C. The test sample prepared from catalyst sample C (2% Pt, 10% BaO, and 10% MgO on alumina) exhibits significantly higher oxidation efficiency (> 20%) than catalyst sample A over the entire temperature range from about 250°C to about 500°C. Finally, the test sample prepared from catalyst sample D (2% Pt, 10% BaO, 10% MgO, and 6% Mn on alumina) showed significant enhancement of the oxidation efficiency (72%) from about 400°C to about 550°C.

[0033] Figure 3 provides a series of plots comparing the NO stor-

age efficiency of test samples prepared from sample catalysts A–E before aging. In these experiments, a proprietary monolith and sample showed the greatest storage efficiency with values of over 70% being achieved at temperature from about 300°C to about 450°C. Figure 4 provides a series of plots comparing the NO storage efficiency of test samples prepared from sample catalysts A–E after aging. Each of the test samples prepared from sample catalysts A–E showed a marked drop in NO storage efficiency after aging. However, catalyst samples B (catalyst sample A + 6% Mn) and D (2% Pt, 10% BaO, 10% MgO, and 6% Mn on alumina) showed higher efficiencies than sample A and E over the temperature range from about 350°C to about 500°C. Moreover, the test sample prepared from catalyst samples B had an efficiency over 20% in the temperature range from about 360°C to about 540°C and the test sample prepared from sample catalyst D had an efficiency over 20% in the temperature range from about 390°C to about 600°C.

[0034] While embodiments of the invention have been illustrated and described, it is not intended that these embodiments illustrate and describe all possible forms of the invention. Rather, the words used in the specification are words of

description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the invention.